Field Testing of Co-Disposal Techniques for Acid Generating Tailings and Waste Rock at Cerro de Maimón Mine

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Abstract

The mining industry is ever striving to comply with increasingly stringent environmental regulations through innovations in mine waste management. In recent years, innovative technologies have rapidly developed to effectively store and manage mine waste as a means of reducing environmental impacts through the entire life cycle of the mine development, from start-up, operations to closure. These technologies include tailings thickening/dewatering and co-disposal/co-mingling with problematic waste rock. This paper presents development of a co-disposal technique for the Cerro de Maimón Mine located in the Dominican Republic, where both tailings and waste rock are acid generating. The conventional slurry tailings were thickened to a non-segregating consistency to facilitate co-disposal of the tailings and waste rock. A large scale field experiment was carried out to investigate the effectiveness of different co-disposal methods through two stages of the investigation. Stage 1 involved deposition of acid generating waste rock on an existing tailings beach and Stage 2 involved deposition of waste rock and tailings in layers of different thicknesses. Two test cells were constructed at the site: one cell for tailings and waste rock deposition in approximately 1 m thick layers; and the other cell for deposition in approximately 2 m thick layers. Tailings samples were taken prior to and after waste rock placement using thin walled samplers. Field instrumentation included moisture sensors and settlement plates. The in-situ properties of the tailings were characterized through both field and laboratory testing programs including field vane tests, self-consolidation tests, soil water characteristic tests, suction measurements and moisture content profile determinations. The results of the field experiment indicate that co-disposal represents a feasible means to increase storage efficiency and reduce environmental impact of the mine wastes.

Introduction

It is well recognized that the co-disposal of tailings and waste rock can provide many benefits for the mining industry. The main benefits include reducing the long term liability of mine waste facilities by minimizing acid rock drainage (ARD) and reducing environmental impact footprint by combining the tailings impoundment and waste rock facilities. The concept of the co-disposal of mine waste materials was introduced in the early 90’s (e.g. Williams and Kuganathan 1992) and the technology was pioneered in coal mine waste management (William and Gowan 1994). Subsequently, the technology was tested for gold mine tailings (e.g. Johnson et al. 1995). Since then, there has been significant research conducted to investigate different co-disposal methods and the resulting effects on the
properties of the tailings and waste rock. The different methods may be classified based on the degree of waste rock and tailings contact:

- Layered co-disposal: tailings and waste rock are deposited in layers with contact between alternating layers;
- Non-layered co-disposal: tailings and waste rock are deposited in different areas in the same facility;
- Co-mingling: tailings and waste rock are blended and mixed to generate a relatively homogeneous composite material.

Independent research programs have investigated the above methods. For example, Lamontagne et al. (2000) demonstrated that layered co-disposal of tailings and waste rock may delay the onset and reduce the magnitude of acid mine drainage production since the layers of tailings limit the mobility of water and air in waste rock and can act as a capillary barrier to maintain saturation of the waste rock as well as to minimize the diffusion of oxygen in the waste rock dumps. Williams and Currey (2002) demonstrated the feasibility of an in-pit co-disposal method and the improved closure strategies for the Kidston Golder Mine in Queensland, Australia. Wickland and Wilson (2005) carried out mesoscale column tests on the mixture of waste rock and high density tailings and identified an optimum mixture ratio for the geotechnical performance of the tailings and waste rock composite materials. The mixture of waste rock and tailings may increase the resistance to ARD due to the relatively low hydraulic conductivity and lower air entry value of the mixture (Wickland et al. 2006a). Furthermore, Wickland et al. 2006b developed a design approach for homogeneous mixtures of tailings and waste rock. The waste rock and tailings can be mixed to produce an engineered cover material (Wilson et al. 2009).

The co-disposal methods ranging from non-layered, layered to co-mingling may increase the level of effort in handling of materials during operations. This paper is focused on the investigation of the layered co-disposal method through field scale deposition trials carried out at the Cerro de Maimon Mine.

**Project Background**

The Cerro de Maimon Mine, operated by Perilya Limited (Perilya), is located about 75 km northwest of Santo Domingo in the Dominican Republic. The project involves mining and milling oxide ores and sulphide ores bearing gold, copper, silver and zinc minerals with a production rate of about 2,500 tpd. Geochemical characterization studies indicate the sulphide ore, footwall waste rock and all the tailings are acid generating. The challenges during the design of the tailings and mine waste management system included the limited space available and prevention of acid generation of the mine wastes.

A co-disposal facility (CDF) was designed for the storage of potentially acid generating (PAG) waste rock and thickened tailings as a means to improve the properties of the tailings and reduce the size of the waste management facilities. Tailings are thickened to $\pm 55\%$ solids prior to deposition. The design concept of the CDF was discussed in detail by Wislesky and Li (2008).

The existing CDF consists of three adjoining cells where tailings are end discharged. Acid generating waste rock is then end dumped and pushed by dozer over the tailings surface. Effluent and runoff is decanted to a separate water management facility located downstream of the CDF for treatment prior to reuse or discharge.

Field deposition trials were carried out at the existing site. The results of these experiments were utilized to develop an optimized strategy for the co-disposal of PAG waste rock and tailings within the CDF, such that the capacity of the CDF was maximized and environmental impacts minimized. This
paper presents the results of deposition trials carried out in the field and the requirements for further study.

The investigation of the co-disposal method consisted of two stages:

- **Stage 1:** Direct deposition of PAG waste rock on an existing tailings beach; and
- **Stage 2:** Deposition of tailings and PAG waste rock in two instrumented test cells in layers followed by in-situ testing.

### Initial sampling and testing procedures and results

#### Procedures

Prior to carrying out co-disposal testing, it was important to develop an understanding of the basic characteristics of both the tailings and waste rock. Initial sampling and testing in the field and laboratory was undertaken to characterize the physical properties of the tailings that were freshly deposited on the tailings beach as well as the properties of the PAG waste rock. The tests carried out included moisture content profiling of the existing beach, settlement measurements of the tailings deposition, shear vane tests along the trafficable and fresh tailings beach and assessing the key physical properties of the waste rock through grain size and void ratio (porosity) testing. The testing and data collection procedures are described below.

#### Shelby Tube Sampling

The initial moisture content and void ratio of the deposited tailings within the upper 0.6 m depth, was determined by testing extruded Shelby tube samples of tailings. The relatively low shear strength of the tailings did not allow for heavy equipment access, therefore all sampling was completed on the tailings beach by hand. Wooden boards were placed on soft tailings to allow for access and sampling into the tailings beach and to minimize boundary effects.

The following procedure was used for obtaining the undisturbed tailings samples:

- The outside and inside of 76mm (3 inch) diameter Shelby tubes were lubricated with dish soap to reduce frictional effects during sampling.
- The Shelby tube was pushed into the tailings by hand slowly and the top of the tube was sealed with wax prior to withdrawal.
- The Shelby tubes were then pulled out of the tailings (suction forces kept the sample in place). In desiccated tailings, the tailings outside of the Shelby tube were excavated to retrieve the tube.
- The bottom of each Shelby tube was then sealed with wax, and the sample transported to the mine’s lab in an upright position.

At the lab, samples were extruded from the Shelby tubes using a “custom-made” plunger fitted to the inside diameter of the tube. Samples were extruded in approximately 5 cm lengths and placed in an oven at 110 °C for a minimum of 24 hours.

#### Shear Vane Testing

Shear vane profiling was carried out along the tailings beach utilizing a hand vane tester (a RocTest M-3 hand vane) with an extension, which can reach up to a maximum depth 2.1 m below ground surface. In accordance with the operating manual (Rocktest 2000), the following procedures were followed to measure the field vane strength profile:

- The vane was pushed into tailings and at a specific depth and the vane was then rotated at a rate of 12 rpm to measure the peak strength.
After peak shear strength was measured, the vane was rotated quickly 25 times, and the remoulded shear strength measured.

The vane was pushed deeper into the tailings and the peak and remoulded shear strength measuring procedure was repeated.

A shaft friction profile was measured by replacing the vane with a dummy rod at a location within 0.3 m (laterally) of the test location.

**PAG Waste Rock Sampling and Testing**

Relevant physical properties of the PAG waste rock are the void ratio and grain size, as these factors affect the frequency and volume of pore space which the tailings can occupy. Representative grab samples of the waste rock were taken for laboratory testing of these parameters using appropriate ASTM standards.

**Initial Conditions**

The initial conditions of the tailings beach in terms of moisture content and undrained shear strength were determined prior to commencement of the Stage 1 test. The tailings beach was moderately desiccated at the time of sampling. Figure 1 presents the moisture content profile of the upper 0.6 m of the tailings along the tailings beach from the west side, the centre to the east side at approximately 25 m intervals. The moisture content profiles suggest that the tailings deposit exhibited layering properties due to deposition and desiccation cycles.

![Figure 1: Tailings beach moisture content profile prior to PAG waste rock deposition.](image)

Figure 2 provides the tailings beach shear strength profile, prior to deposition of PAG waste rock. A strong correlation was observed between shear strength and depth below surface. The strength developed was significant due to self weight consolidation and desiccation.
Stage 1 - Co-disposal Investigations

The objective of Stage 1 testing was to determine the feasibility and effectiveness of using equipment available on site to co-dispose and/or co-mingle PAG waste rock and tailings. Two methods were tested for waste rock placement over previously deposited fluid or desiccated tailings: spreading by dozer; and placing by excavator. The PAG waste rock produced from the mine for the test consisted of approximately 62% gravel, 26% sand and 12% fine size particles, with an average porosity of 0.26 (a void ratio of 0.35).

Dozer Spreading of Waste Rock on the Existing Tailings Beach

Co-disposal was first assessed by dozing PAG waste rock onto both the desiccated and fluid tailings beaches to monitor heavy equipment accessibility, and to investigate potential co-mingling mechanisms of the waste rock and tailings during deposition (i.e. filling the voids in the waste rock with tailings) and the effect on consolidation of the tailings.

PAG waste rock was hauled from the mine to the test site using articulated trucks, and was then spread over the tailings by a dozer. On the desiccated tailings beach, waste rock was spread directly on the beach as thin as possible for equipment access. On the fluid tailings beach, a cell approximately 25 m wide and 40 m long was constructed with perimeter berms to contain fluid tailings during waste rock placement. For both tests, test pits were excavated to measure the rockfill thickness and to observe the extent to which tailings infiltrated into the waste rock voids due to penetrating and compressing forces of gravel size particles of the waste rock.

Results and Observation (Dozer Placement)

Figure 3a shows the placement of the PAG waste rock on the desiccation tailings beach. The following observations were made pertaining to PAG waste rock placement on the desiccated tailings beach:

- The desiccated beach was accessible to articulated trucks after placement of 1.3 to 1.5 m of PAG waste rock;
- Heave of tailings was developed at the front of the PAG waste rock advancement;
- Water migrated onto the tailings surface due to compression and consolidation of the tailings;
- Test pits dug through the PAG waste rock revealed a distinct tailings-PAG waste rock boundary and no significant penetration of tailings into PAG waste rock void spaces was observed; and
- The PAG waste rock was saturated up to the middle of the layer.

The following observations were made regarding PAG waste rock placement on fluid tailings:
Tailings liquefied under the static load imposed by the PAG waste rock and observed as “boils” at the front of the PAG waste rock advancement. Photo two in Figure 3 shows an example of the liquefied tailings at one location; Tailings were mostly displaced by the PAG waste rock during deposition; Test pits dug through the PAG waste rock revealed a tailings-PAG waste rock boundary at 2.4m; No significant tailings ingress into the PAG waste rock void spaces was observed.

Summary for Dozer Placement Technique

Based on the above observations, it was concluded that the tailings beach becomes accessible for heavy equipment, including both the trucks and dozers used at the site, after being desiccated and can provide sufficient foundation support for waste rock placement. Direct dozing of waste rock onto freshly deposited tailings was not sufficient to generate a mixing mechanism. One of the contributing factors was the high fines content and low void ratio of the waste rock, which did not permit significant tailings slurry infiltration into the waste rock void spaces.

Excavator Dropping of Waste Rock on the Existing Tailings Beach

Co-disposal utilizing an excavator to place PAG waste rock by dropping it into fluid tailings was also assessed. The excavator was positioned on a containment dyke and was used to drop PAG waste rock from the maximum height possible (~4m) into the test cell filled with fluid tailings. After waste rock filled the entire test cell, the excavator dug a test pit to investigate the extent of tailings and waste rock mixing.

Results and Observations (Excavator Placement)

Observations were made during the placement of waste rock utilizing an excavator to drop it onto the tailings beach. The observations were as follows:

- Pockets and lenses of tailings were noticed within the waste rock in several locations in the test pit as shown in Figure 4a;
- Tailings did not enter the void space of the waste rock to any significance.
- A tailings and waste rock interface appeared to be at a depth of about 1.4 m with some minor mixing observed at this interface within a 20 cm zone as shown in Figure 4b.
Summary for Excavator Placement Technique

Observations suggest that the formation of the pockets of co-mingled PAG waste rock and tailings was due to the dynamic impact of dropping waste rock. However, the degree of the mixing of tailings and waste rock was relatively insignificant to achieve uniform co-mingling.

Stage 2 – Performance investigation

In general, Stage 1 testing showed that both the dozer and excavator placement techniques utilized were effective at constructing a waste rock layer/pad over top of desiccated and freshly placed tailings; however, neither method was effective at mixing tailings with waste rock. In other words, co-mingling of PAG waste rock with tailings does not appear to be viable at this site due to the high fines content and well graded nature of the waste rock; additional effort to mix the materials would be required.

Stage 2 testing was developed to quantify the potential benefits resulting from the placement of PAG waste rock layers over deposited tailings, by monitoring the geotechnical performance of the tailings and waste rock in a layered deposition scheme.

As observed during the Stage 1 investigation, the deposited tailings were compressed by waste rock and pore water was expelled into the waste rock or to the surface. These findings suggest that waste rock can provide a preload to consolidate tailings as well as a drainage layer to shorten the drainage paths in a layered system, which accelerates consolidation. Compression of the tailings resulting from the waste rock load provides more efficient waste disposal compared with discrete storage facilities. Stage 2 testing was designed to estimate these benefits with the following considerations:

- To determine moisture loss and density increase of the tailings due to one layer of PAG waste rock placement;
- To estimate storage volume gain resulting from compression of tailings under the PAG surcharge.
- To investigate the strength gain of the tailings resulting from PAG waste rock placement; and
- To identify an optimal thickness of the PAG and tailings layers to maximize the benefits.

Stage 2 Investigation Methodology

Two co-disposal test cells were constructed to facilitate Stage 2 testing. The berms of the test cells were constructed of PAG waste rock with average dimensions of 9 m x 9 m on a waste rock platform. The depths of Cells 1 and 2 were designed for 1 and 2 m thick deposits of tailings, respectively. Test cells were instrumented with moisture sensors connected to a data logger with readings taken at 30
minute intervals. The following procedures were used to set up the experiment and collect the required data:

- Installed moisture sensor loggers, staff gauge, and settlement plates in each cell in the centre area as shown in Figure 5;
- Directly discharged thickened tailings into Cell 1 to a 1 m thickness and into Cell 2 to a 2 m thickness;
- Waited for consolidation and desiccation to take place and observations of cracks beginning to develop at the surface of the tailings;
- Took daily settlement readings of tailings surface and daily survey of settlement plates;
- Carried out sampling and suction measurements using a hand-held tensiometer;
- Refilled the test cells on day 13 up to 1.0 m and 2.0 m thick for the tailings deposits for Cells 1 and 2, respectively, then allowed for consolidation and desiccation.
- Carried out shear vane profiling using an M-3 hand vane and suction measurements throughout the desiccation process;
- Obtained Shelby tube sample of the tailings together with bulk samples at the surface for moisture content determination, prior to PAG waste rock deposition;
- Install settlement plates on the tailings surface prior to waste rock placement;
- Spread 1 m thick PAG waste rock lift over each test cell in a 1 m thick lift (Figure 4), continue daily survey of settlement plates;
- After cessation of settlement (approximately 6 days after PAG placement), PAG waste rock was removed from a patch in each cell via excavator to allow for a shear vane profiling and Shelby tube sampling of tailings;
- A second 1 m thick PAG lift was spread over both test cells. After 27 days the above step was repeated, marking the end of the experiment.

![Figure 5: View of Cell 2 during initial fill.](image)
Observations and Results of Investigation

The following visual observations were made throughout the duration of the test:

- The tailings settled the most in the centre of the cell and desiccation cracks started to develop 7 to 10 days after deposition;
- Two layers of thickened tailings were deposited in the test cells. The thickener underflow had 45% solids content for the first layer and 55% solids content for the second layer;
- During waste rock placement, some heave movements developed at the front of the waste rock when the placement was relatively fast. Subsequently, the speed of waste rock placement was at a controlled rate to minimize shear deformations.

The following section outlines the monitoring data obtained with an interpretation of the results of the Stage 2 co-disposal performance investigation.

Self Weight Consolidation and Desiccation Settlement

Surface settlements were measured by reading the staff gauge installed in each test cell. Settlement readings were taken throughout the test duration to correlate tailings property changes with consolidation of the material. Figure 7 shows the observed settlement of Cell 1 and Cell 2 tailings surfaces prior to PAG placement. In both test cells the majority of settlement occurred within 4 days of deposition. The tailings were then allowed to desiccate for 10 to 15 days, after which point no significant settlement of the tailings surface was measured.

Figure 7: Tailings surface settlement prior to PAG waste rock placement
Suction Measurements

A hand held QuickDraw tensiometer was used to measure the suction developed after the tailings had undergone moderate desiccation (i.e. shortly after desiccation crack formation). Figure 8 represents the suction profiles at various stages of desiccation. As is shown in Figure 8, the depth of the desiccation occurred with the upper 10 to 20 cm with measureable suction.

![Suction Profiles](image)

**Figure 8:** Measured suction profiles

Tailings Compression under PAG Rock

The compressive settlement of the tailings due to PAG rock loading was estimated using survey data of the settlement plates installed at the top and bottom of the tailings layers.

Significant consolidation of tailings resulting from PAG placement was observed within 1 day of placement. Placement of the 1st PAG lift resulted in 5.7 cm and 14.6 cm of settlement for Cells 1 & 2 respectively. Consolidation beyond the first day was negligible. This indicates that the consolidation of the tailings took place fast as a result of two way drainage provided by the waste rock. The total settlement was approximately 7.4 cm and 16.6 cm (i.e. approximately 10% strain) for the tailings in Cells 1 and 2, respectively.

Moisture Content Profile

Moisture content profiles were determined in the laboratory on the samples taken from each deposition test cell during each stage of the experiment: preceding 1st PAG lift placement, preceding 2nd PAG lift placement, and a final sampling at the end of the test. Shelby tube samples taken from Cell 1 after the 2nd PAG lift and from Cell 2 prior to the 1st PAG lift were damaged during transportation. Figure 9 shows the measured moisture content profiles.

![Moisture Content Profiles](image)
Figure 9: Moisture profiles measured at different stages

Prior to PAG rock deposition, the moisture content profile exhibited a decreasing trend in the upper zone due to desiccation, increasing with depth in the middle zone and decreasing with depth in the lower zone due to self weight consolidation.

Following placement of the 1st PAG lift, Cell 1 tailings underwent an average moisture content reduction of approximately 11%, corresponding to a reduction in void ratio of approximately 0.35.

Moisture content profiling in Cell 2 exhibited similar trends, although initial moisture content conditions prior to PAG placement are not available due to a damaged Shelby tube and only one data point was obtained using a bulk sample. Placement of a 1 m thick PAG lift over 2 m of tailings resulted in an average moisture content decrease of 7.5%, corresponding to a void ratio reduction of approximately 0.23. Placement of the 2nd PAG lift yielded slightly additional changes in moisture content.

The results of the moisture content profiling suggested that layered deposition of PAG and tailings significantly reduces the void ratio of the tailings. As is anticipated, the 1 m thick lift of tailings experienced a greater decrease in moisture content than the 2 m thick lift of tailings.

The inferred dried density of the tailings increased from approximately 1.3 t/m$^3$ to 1.5 t/m$^3$ for the tailings in the test cells.

In-Situ Undrained Shear Strength

Shear strength profiles of the tailings in the test cells were measured prior to and after PAG waste rock lifts and the results are presented in Figure 10.

Figure 10: Vane shear strength profiles measured at different stages

It is evident that placement of the PAG surcharge loads resulted in significant increases in the undrained shear strength of the tailings deposit. Placement of the 1 m thick lift resulted in a strength increase of 62 – 210% from the surface to the bottom. Placement of the 2nd PAG lift resulted in a net strength increase of 25 – 42% from the surface to the bottom.
Discussion

Co-Disposal at the Cerro de Maimon Mine Site

The main driver for co-disposal of PAG with tailings at the Cerro de Maimon mine site was the limited area available for construction of separate disposal facilities and the effectiveness of management of potential acid generating wastes. The other considerations for the use of the layered co-disposal method include improvement in stability of the facility, reducing liquefaction potential of the tailings deposit under possible seismic events and ease of water management. Co-disposal deposition can keep waste rock saturated and prohibit acid generation during operation. After closure, the compressed tailings layers will hinder oxygen diffusion and reduce ARD reaction.

The results of the deposition tests showed that layered deposition of tailings and waste rock is feasible, after allowing for consolidation and moderate desiccation of the tailings deposit, and that an increase in density and shear strength of the tailings can be realized shortly after placement of a waste rock layer. The increase of the storage volume was significant for both the 1 m and 2 m thick waste rock lifts. For the strength gain and void ratio change, the 2 m thick waste rock lift scheme was comparable to the 1 m thick lift scheme. To provide flexibility in operation, 1.5 m to 2.0 m lifts of tailings and PAG waste rock are considered favourable.

Operational Challenges

Layered deposition of waste rock and tailings can be a challenging procedure that requires specific operating characteristics to be successfully implemented. Layered deposition requires careful planning to ensure that the design objectives are met. The production of waste rock and deposition schedules are two key factors in this regard. At the Cerro de Maimon mine, the CDF is internally divided into three distinct cells which provide the required flexibility for successful tailings and waste rock co-disposal.

Consideration also needs to be given to techniques for waste rock placement. Shear strength of the tailings and grain size of the waste rock will dictate the minimum thickness of waste rock lift required for safe equipment access. For this specific site, the minimum waste rock lift was found to be 1.3 m thick to safely operate the equipment; however this could vary depending on the accelerated strength gain of the underlining tailings resulting from the placement of waste rock layers, as illustrated herein. Placement of waste rock on the tailings beach should be at controlled rates allowing for consolidation of the tailings to take place during deposition. Equipment access into the facility must also be maintained to allow for trucking and dozing PAG waste rock. If the tailings management facility is lined with geosynthetic liners, special consideration must be given to protect the liners. For the Cerro de Maimon CDF, the access roads were designed with careful material selection and required careful construction to minimize damage to the liner system.

Summary

The field deposition trials carried out at the Cerro de Maimon mine demonstrates that layered co-disposal of PAG waste rock and tailings is feasible to increase the storage capacity and to reduce environmental impact of, the tailings management facility for the project. Co-disposal employing layered deposition of the waste materials was observed to provide significant quantifiable benefits including significant increase in density and shear strength of the tailings deposit, and acceleration of tailings consolidation by shortening the drainage paths. The increase in density of the tailings due to layered co-disposal deposition would also decrease liquefaction potential of the tailings during seismic events. Thickened tailings also facilitates development of uniform tailings beaches, which require moderate desiccation over relatively short periods of time so that the placement of the PAG rock can be
carried out using trucks and dozers for PAG waste rock placement. Co-mingling of PAG waste rock and tailings requires further investigation when the fines content of the waste rock is variable. Where the PAG waste rock becomes significantly coarser, it may be possible to fill the void space in the waste rock with thickened tailings and thus further increase the storage capacity of the facility. Other means of mixing should also be investigated in co-disposal research.

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References


